Students' reflection on experimental design during an innovative teaching sequence with LabBook

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STUDENTS' REFLECTION ON EXPERIMENTAL DESIGN DURING AN INNOVATIVE TEACHING SEQUENCE WITH LABBOOK

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Abstract: Experimental design learning activities have been shown to foster the acquisition of scientific abilities and to favour sense-making. A teaching sequence is proposed to second year university students whose goal is to make them experience experimental design and reflect on the design process. The writing part of the students' design work is supported by a computer-based platform, LabBook, devoted to experimental design work. Students go through three experimental situations that are organized in a role-playing game. They have to design an experiment and to write the procedure that will be performed by another student. The students' reflections, collected in written reports, are analysed using a list of criteria that were designed for experimental procedures assessment. Reflecting on their successive roles as designers, technicians and silent observers, the students become aware of experimental design stakes. Observing a technician who tests the experimental procedure appears very efficient for experimental assessment and it does help students to gain assessment skills. The role-playing game makes them focus particularly on the communicability qualities of a written procedure. Since the procedure must lead the technician to collect the expected results successfully, the designers deal with communicability together with executability (feasibility, temporal and safety constraints) and data quality aims. The students point out accurately the difficulties of writing tasks, especially the balance between concise and complete or detailed description. The procedure editor of LabBook, Copex, appears very useful to them, being able to fulfil their requirements for organising and documenting a written experimental procedure. The role-playing game incites the students to deepen the scientific reflection and improves the organisation of their work. However, relevance criteria are more difficult to grab and fulfil. The experimental situations do not have the same ability to reveal these criteria to students and to make them reflect and evolve.

Keywords: Experimental design, Inquiry-based teaching, Laboratory Work in Science, Computer Supported Learning Environments

INTRODUCTION

Several researches emphasize the importance of experimental design. Karelina and Etkina (2007) find that students who design their own experiments, engage in behaviours that are much closer to the ones of scientists than did students working in traditional laboratories, because they spend more time "making sense". Etkina et al. (2010) find that when students are used to design experiments, they develop further scientific abilities (*i.e.* procedures, processes, and methods that scientists use when constructing knowledge and solving experimental problems).

In our research we put a focus on the experimental procedure, which is an authentic scientific object. When a scientist designs an experiment, at the end of the process she/he will produce scientific results. She/he has also to write down the experimental procedure that describes precisely how these results can be obtained. Students who study experimental sciences know from laboratory work that a procedure is compulsory in order to run an experiment. In this study, students are asked to design experiments and to write down the procedure. However, previous researches have shown that students are reluctant to write (Girault, Cross, & d'Ham, 2007). But, writing supports sense-making and conceptual changes (Keys, 1999), because perception precedes knowledge building, and it is an important element before the comprehension phase (Prain & Tytler, 2007). Furthermore teachers would like the students to write a procedure that looks like a scientific one and that can be used in the laboratory.

We present a teaching sequence which goal is to make second year University students reflect on the process of designing experiments. A computer environment, LabBook, supports the writing part of the students' experimental design work. We question the students' perception of the experimental design and explore how LabBook can help them. These results focus on what the students say rather than on what they do.

The goal of this study is to answer the following research questions.

- How do students deal with the communicability during the learning process?
  - We believe that the role-playing game will force students to consider communicability that is usually difficult for them to handle.
  - We provide students with LabBook (and more particularly Copex, one of LabBook's tool) that can be helpful to structure a procedure (the structuration is part of the communicability).
- Do the students give too much emphasis to communicability to the detriment of the scientific aspects (criteria of executability and relevance)?

THE TEACHING CONTEXT

We present a teaching module aimed at second year university students who want to discover science with a different focus. In this module, students experience experimental design through practices in biology, physics and chemistry, and reflect on the design processes. Teaching is organised around three situations where pairs of students have to design an experiment starting from a scientific question.

The role-playing game

There are tricks to help the students to motivate them in writing a correct experimental procedure. One trick that we have used in previous studies (Marzin & Vries, 2013) is to ask the students to write a procedure for somebody else who will perform the experiment. It is even better when the "somebody else" is a real someone and furthermore if she/he does perform the experiment.

In the present case, each situation is organised as a role-playing game. The students are working in pairs of *designers*: they have to design an experiment and write down a procedure. One of the designers becomes a technician and the other one, an *observer*, watching silently a *technician* coming from another group. The technician performs the observer's procedure and reflects aloud, while the observer listens to her/his comments and takes notes. Afterwards, the students discuss together. They have to reflect and write a report on their work as designers and technicians, and about the experimental procedure and the design process. Guidelines (Table 1) are given to the students to guide their reflection. After each situation, an oral debriefing is organized with all the students and the teachers (several teachers who have competencies in different disciplines are involved).

Details of the learning situations

- Situation S1 (2 hours) is a discovery situation. Two scientific questions are given to the students. The students are not familiar with the chosen topics, but they are easy to grasp, so the students can easily design and follow the role-playing game within 2 hours. In the role-playing, a *technician* runs the experiment of the topic that she/he has not designed. For their report, the teachers ask them to answer questions about the work and abilities of a designer and of a technician. The students also have to reflect about what is an experimental procedure, and what would be the qualities required for a good procedure.

- Situation S2 (4 hours) proposes the same scientific question for all the students. The students are familiar with the topic and the question is more complex than in situation S1: the students already had classic “cookbook” laboratories on this topic during their studies (high school and first year at university). On top of that, the technicians may be considered as experts since they played the designer role before being technician. For the report, students are asked to reflect about criteria to assess an experiment and its procedure. A list of criteria for experimental design assessment is built with the whole group of students at the end of Situation S2. The produced list is very similar to the one published by the authors (Table 2) (Girault et al, 2012). This list is to be used to assess situation S3.

For situations S1 and S2, the teachers give the playing rules and do not intervene except to help with the experimental material and devices during the design phase, if required by the students. The teachers organise and regulate the debate in the debriefing session.

- Situation S3 is a longer-term project (10 hours). Each pair of students work on a different topic. A test with a technician/observer role-playing is organized at the end, but students may organise intermediate tests with a technician during the 10 hours. In situation S3, each teacher has a tutor role: he/she answers questions, provides advices, devices and material on request. Two 30 minutes appointments with the tutor are organized between class sessions for S3, for each group of students. At the end of S3, students write a final report, which is more complete than the previous short reports. A framework is proposed for this final report (Table 1). Part of this final report is dedicated to analyse and comment the design process through their experience, and students are asked to explain the difficulties they have encountered and how they have solved them or not. This leads students to write a narrative of their work on a meta reflection level. The students' work is assessed through this final report and an oral presentation.

Table 1. Guidelines that have been given to the students for guiding their meta-reflexion about experimental design. (In the case of S3, the initial guidelines required improvement and they were modified after the first semester. The guidelines listed below are the final ones).

S1	*During the session* What happens while designing an experiment? What competencies are at stake? Same question when performing the experiment for the designer/for the technician *S1 report guidelines* What definition of an experimental procedure will you give? What competencies are necessary to write the procedure? What should be the qualities of an experimental procedure?
S2	*During the session* What are the qualities and defects of the procedure you have designed? Same question for the procedure that you have tested. *S2 report guidelines*: *building criteria for experimental procedures assessment* Did the technician perform what was written? If not can you explain where the problem comes from? Do you plan to modify your procedure and why? What was ok? In both cases, try to identify the criteria that are at stake.
S3	*Final report guidelines* 1. Description of the scientific problem, the experiments designed, the results 2. Design work: description of complementary work that was needed and results. Encountered problems and solutions found. Evaluation and discussion of the final procedure taking into account the test performed by the technician(s). 3. Reflecting on the design work: Description of the questions and problems encountered, of the resolution processes and the competencies required. Criteria that were the most difficult and the easiest to handle. What did you learn, what interested you?

The topics proposed to students are diversified regarding the themes but also considering the familiarity of the students with a topic. It can be totally new (and rather simple) or well known and already experienced in traditional laboratories. All these situations bring awareness on various points that depend on the topic: new theoretical knowledge, the stakes of experimental strategies, details such as how to choose the value of a parameter, the mastery of a technique and/or of a measurement device, … Well known situations are not an advantage because students had experienced them in cookbook type laboratories and can be surprised when they discover the underside of it and its complexity.

The LabBook platform

In S2 and S3, the written part of the experimental work is performed on the LabBook platform. LabBook has been especially designed to support the experimental design work of high school and university students. LabBook (http://labbook.imag.fr) is an inquiry learning environment that supports the collaborative and online elaboration of a scientific experimental report by students (or notebook). Unlike other inquiry learning environments, LabBook is not organized according to the inquiry cycle but according to the notebook to be produced by the student(s).

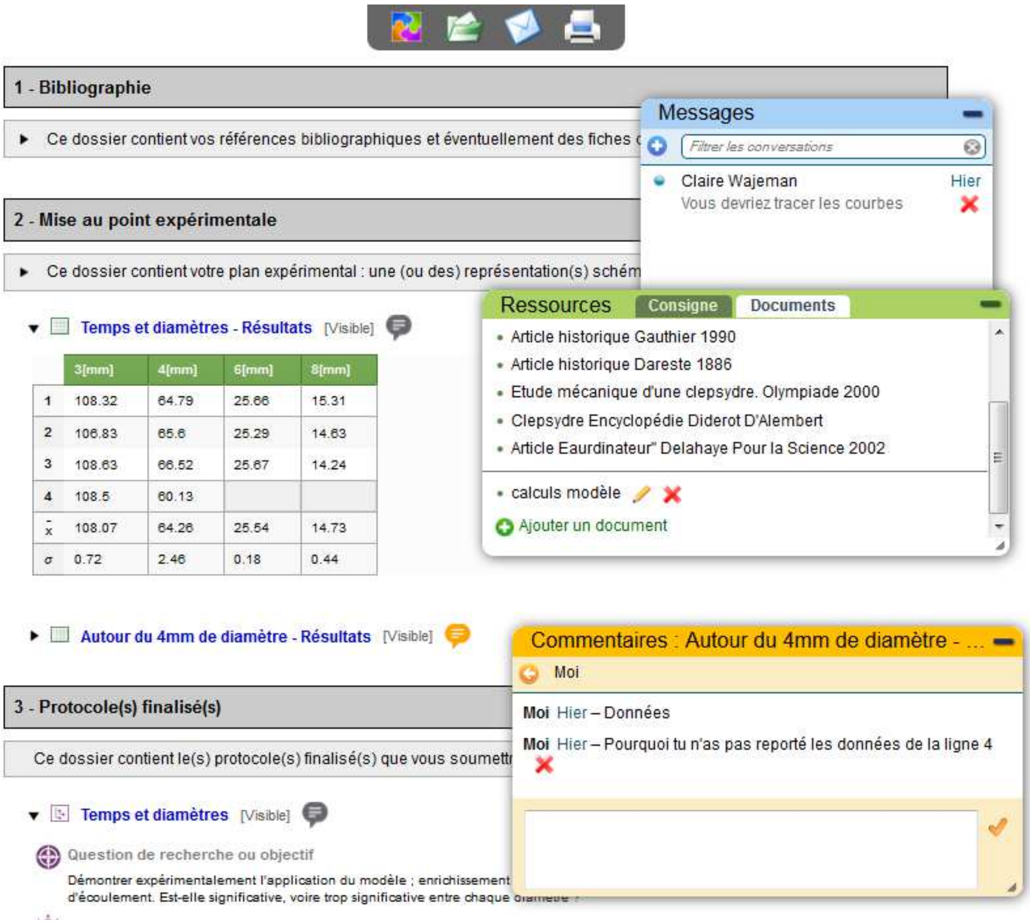

Figure 1. Current LabBook interface of a student's report.

LabBook can be used for any scientific topic and the teacher structures the student task by configuring the workspace of the student. Figure 1 displays one LabBook notebook written by a pair of students for their project work (S3). It is structured by the teacher in several sections: in Figure 1 the visible sections are 1-Bibliography, 2-Experimental development and 3-Final procedure. Each section contains the documents, called LabDocs, produced by the students (initial documents may also be proposed by the teacher). There are four types of LabDocs, editable with the four different tools embedded in LabBook: a text editor, a drawing tool, an experimental procedure editor (Copex tool), and a tool for editing, processing, and modelling experimental datasets (Fitex tool). In Figure 1, the Labdoc "temps et diamètres- résultats" (ie "Results for time versus diameters") is produced with Fitex. In this case, the students use Fitex to gather and process their experimental data. Figure 1 also displays the beginning of an experimental procedure, which title is "temps et diamètre" produced with Copex. LabBook provides other services: the resource widget (green window in Figure 1) contains the mission statement and the reference documents (provided by the teacher or collected by the students); the communication widget (blue window in Figure 1) and the LabDoc comment widget (yellow window in Figure 1) facilitate remote collaborative work. All these functionalities make LabBook an innovative inquiry learning environment, with two original tools that are specific to experimental design: Copex and Fitex.

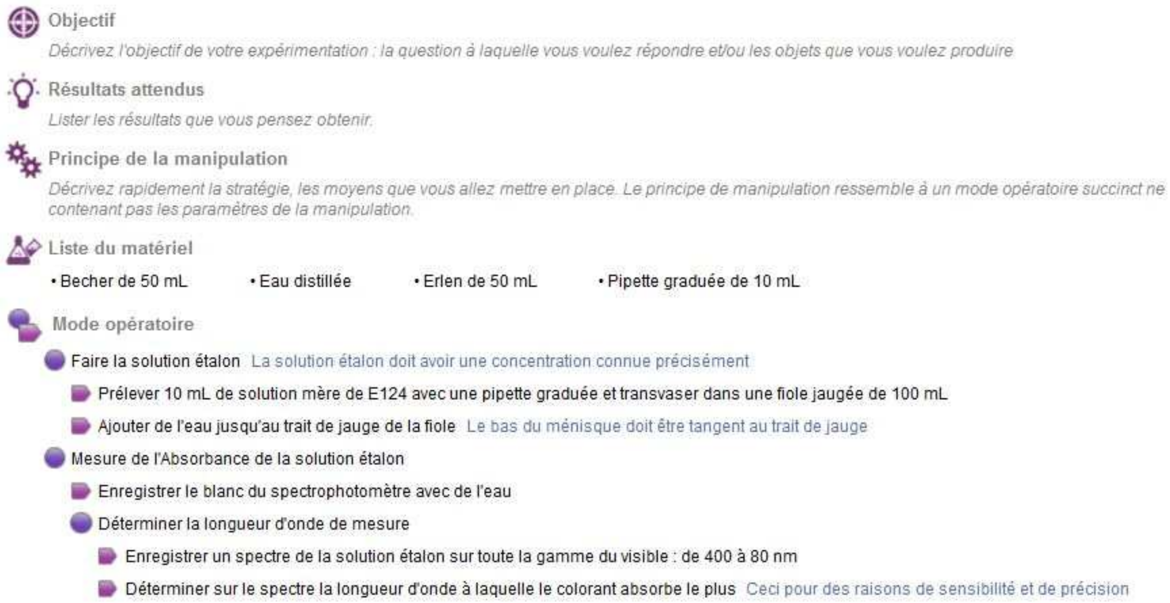

Figure 2. Screenshot of an experimental procedure written with Copex (in French) that shows the structuring offered by this tool.

The procedure editor, Copex, proposes several introductory rubrics before the experimental procedure itself (the modus operandi). In the example on Figure 2 there are four introductory rubrics: Experiment objectives, Experiment expected results, Experiment principle and the List of material. The students can organise the experimental procedure in a hierarchical way with steps and actions. They can add extra information in a coloured text field named "comment", connected to each rubric, step or action. Students use LabBook for situations S2 and S3.

METHOD AND DATA

The teaching module was repeated during four semesters. Only motivated students attend this module during one semester since it is an extra module in their curriculum. 41 students follow the complete module. Theses students follow a degree with a major in biology, biology and chemistry, chemistry or physics, and even one student studies computer science.

We collect data during the four teaching semesters: 65 reports are collected and analysed (20 for S1, 26 for S2 and 19 for S3). In the case of S3, the procedure evolves during the process. We only consider the final procedure.

In this paper, we only analyse the students' reports produced after S3 and we focus on the reflection on the design work, i.e. mainly section 3 (see Table 1).

We perform a qualitative analysis of the reflection of the students collected in the reports according to the list of criteria described in Table 2 (Girault et al., 2012). There are three categories of criteria: the two first categories deal with the relevance and the executability of the experiment while the third one assesses the qualities that are specific to the written part, ie to the procedure. It is used as a research grid to categorise and look for the students' difficulties and abilities. As described before, this list has also been built with the students during S2, and they are invited by the final report guidelines to use it as a tool to assess their experiments and procedures and to guide their meta-reflexion about experimental design.

This study focuses on the communicability criteria and on the bridges that students build between communicability and the two other categories, relevance and executability.

We coded each sentence of the students' report according to the sub criteria of Table 2. We encountered some difficulties since the students often express general ideas especially when they want to synthetize and summarise information. Thanks to the report guidelines that lead them to make detailed narratives, in many cases the generality in the text can be contextualised and linked with what the students have experienced.

Table 2. Criteria to evaluate the experimental design and its description by a procedure.

Relevance: the function of the experiment
External relevance between the hypothesis and the quantity to measure
Internal relevance: measurement strategy (methods and materials)
Quality of data acquisition: trueness and precision
Executability: the experiment in the laboratory conditions
Adequacy between the samples and the domains of validity of the measurement methods and materials
Observation of material constraints (availability, cost, feasibility, hazard control)
Observation of temporal constraints
Communicability: the description of the experiment
Completeness (level of explicitness)
Structuring
Presence of the adequate type of information

RESULTS

As previously said in this paper, we analyse what the students say and not what they do.

The students spend time to write a procedure that fulfils the criteria: because of the tests that they perform as designers and those run by technicians, the students are able to check executability and communicability. With the support of the narratives, we are able to identify the ins and outs of the students' assessments for these two categories of criteria. The case of relevance is trickier. Students often say that relevance is difficult to reach. On the other hand they also often validate the relevance criteria with the argument that their procedure has provided the expected results. It seems that building arguments to defend the relevance of their experiment and of the results remains indeed difficult. As a consequence, the students do not always tell all the details that would be necessary to confirm or refute relevance. For this reason, we mainly discuss in this paper the impact of the role-playing game, which leads us to consider mainly communicability and how communicability is related to executability.

Overview of the students' perception on the three categories of criteria

For their final report, the students are asked what are the most difficult and the easiest criteria they have to handle. This gives us an insight for comparison of the three categories of criteria. Figure 3 summarises the students' answers. In this figure, the students' answers can be for a whole category or may be for only one (or several) criteria in this category. Therefore one student may indicate completeness as the most difficult criteria and structuring as the easiest. In this case, communicability will account in Figure 3 as both the most difficult and the easiest. In 12 reports, students say that communicability is the most difficult, but it is also pointed out 12 times as the easiest. On the contrary relevance criteria are often seen as the most difficult to handle, but it is seldom cited as the easiest.

Working together on the same topic, some students disagree: one may find one criterion difficult while the same criterion is easy for the other student. Depending on the topic and on the problematic chosen by the students, one or several criteria could not be at stake. For some students, some criteria are not a problem because they are used to deal with them: for instance, communication criteria (organising, selecting information) are not felt as problematic since these students are used to organise their work. For others a criterion is considered as easy because it is revealed and solved during the test with the technician. When assessing their procedure, as a conclusion, some students discuss the weight of the criteria, especially to tell that they are all important: “you can't neglect one, or you will have troubles with the results/data”.

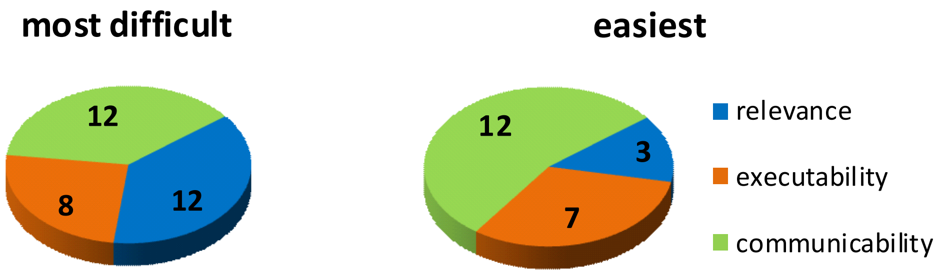

Figure 3. Student’s impression about criteria management. The numbers stand for the number of final reports where the category of criteria is told as the most difficult or the easiest to manage. It can be the whole category as well as one or several criteria of this category.

The students spend a lot of energy for communicability purposes in order to have a procedure which is usable by somebody else (the technician). It can be interpreted as a bias that hinders the scientific part of the work since the writing quality of the procedure is usually not considered as an issue in the scientific work when designing an experiment. The question is it worth or not to make students spend so much energy on communicability? Does it hinder the scientific part of the work? For this we will look for how communicability influences the students’ work.

Focus on the communicability

Fourteen reports provide detailed information about communicability. One pair of students does not seem to bother about communicability. They consider this issue just before running the test with the technician. As the test revealed lots of problems related to communicability and executability, they conclude that such tests have to be repeated until all troubles will be solved. In four other reports, the students mainly deal about the scientific part and we get little information on the writing part and on the tests with the technician. These reports could not be analysed regarding communicability and the role-playing game.

A major point for most of the students is to avoid errors when running the experiment and/or to ensure the proper data quality. That is why the students give a high value to understanding the procedure instructions as well as the procedure goals and strategies. Therefore, they say that everything must be done to avoid misunderstandings: the text must be complete and exclude all ambiguities. It must be efficiently expressed, well structured, clear and concise for easy reading and understanding. These qualities are related to completeness and structuring criteria. One student says that she experiences “doing without understanding” as a technician, which is really unpleasant. Several groups take into account the technician's comfort and pleasure as well as her/his safety. As said by a pair of students, even boredom has to be taken into account, because it may lead to carelessness and thus to errors.

Completeness

Students highlight that the detailed and complete description of actions often contradict concision, and this makes the selection of information quite strategic. Therefore completeness is found difficult to handle. The designers often forget elements that "seem obvious to them", that can be some detail or a minor action of the experiment, a document (such as the technical information for a measurement device), …. The technicians need details but they must not be overwhelmed by information and by too long procedures. One main difficulty is to identify what is really needed by the technician, and what is not. The students follow two main strategies in order to identify the missing useful elements and to achieve completeness: one is "to put themselves in the technician's shoes", and the other is to perform several tests with various technicians. In the former case, they may test the procedure themselves, sometimes several times, before giving it to the technician.

Structuring and type of information

Since an amount of information is generally required, the structuring of the procedure appears fundamental to get an overview of the procedure and a quick and clear understanding of what one is going to do. A high gain is to organise with steps, sub-steps and actions, write short sentences that are easy to understand, use drawings and tables. Copex favours the structuring, and some students report that it was a great help to them for the structuring criterion. In the final report, the experimental procedures are usually written with Copex. Only five reports show procedures written with a text editor. However, four of them follow the structure and organisation of information of Copex. Some students explain the principle at the very beginning, others prefer to split the principle and give it at a lower level, for each step. When using Copex, the students use the “comment” area proposed in the procedure to add theoretical information to justify a task, as well as to detail the execution of a task. The students often want to display additional information (theoretical, technical, results references) for understanding means and add annexes to the procedure. . They also would like to add annexes to the procedure, but this is only possible in the resource part of LabBook but not directly in Copex.

Communicability to ensure executability

From the students' reports, it can be seen that there are bridges between the criteria. Thanks to the role-playing game, they experience, observe and report two fundamental issues: first the quality of the experiment’s execution (executability) and the quality of the produced results (relevance) are very sensitive to the quality of the procedure (communicability). In other words, if communicability is not properly fulfilled, the technician will not be able to properly execute the experiment and the experiment will not provide data with the required quality. Secondly, the procedure has to support executability, and for a number of students, the procedure has to support relevance too. For instance time management and hazard control are often discussed by the students, in relation with communicability (this is presented in more details in this section). Regarding relevance, the students say that the technician has to understand what she/he is doing in order to do it properly. For some students the understanding is limited to the experimental actions performed by the technician. But for others, the technician has to understand the ins and outs of the experiment, i.e. the global strategy and its relevance toward the scientific issues as well as what is at stake for each sub-step of the procedure. Relevance also concerns the quality of data acquisition. However we do not detail this issue here since this criterion is very difficult to grasp from the reflection of the students on their design work. Instead of referring to the reproducibility of the results that is expected in the relevance criteria, most students write about the reproducibility of the procedure that rather concerns the communicability critera.

Communicability versus time management

All the situations make the students aware of temporal constraints. In S3, the students have to make decisions because of time management. If they do not do it for themselves as designers, they have to do it because of the test with the technician. For instance they have to define the scientific issues and the scope of their experiments and the part of the experimental work that will be done by the technician. Temporal constraints also lead them to organize their work and to improve this organisation. So, it has a strong impact on work organisation. Most students carefully check the experiment duration during the test with the technician and sometimes before, especially those who include time management information in the procedure.

Communicability versus hazard control

In S3 the hazard control (safety) criterion is at stake for several topics. Students who have to take into account the safety of the persons, take it very seriously especially because they feel responsible for the technician safety. When possible, some of the designers decide not to let the "dangerous" experimental part to the technician and do it themselves. For instance they prepare a dilution of high concentration solutions of strong acid in chemistry. One student reports that the safety issues lead them to study in depth reaction mechanisms in chemistry that were not among their scientific issues. Students say that this shed a new light on the safety question.

DISCUSSION, THE IMPACT OF THE ROLE-PLAYING GAME

The main reason to introduce this role-playing game in the teaching is to incite the students to write correct experimental procedures. Since we observe that a majority of students spend a lot of time and energy for communicability purposes, we want to check if the effort made on the procedure (evaluated by the communicability criteria) does not hinder the reflection on the content of the procedure (evaluated by the executability and relevance criteria).

Work organisation and communicability

As shown previously about time management, communicability may have an influence on the students' organization because the students want to organise the technician work to save her/him time. Work organisation is also highly motivated by the need to prevent the technician from making errors during the experiment.

Some groups seem really to go far in the organisation of the technician work. This ranges from looking for an efficient structuring of the procedure, guiding precisely the technician work with advices and information displayed in the procedure when needed, giving information about time management for each sub-step of the procedure, organising the data collection in a table in the perspective of data analysis, preparing the calculations and data processing in a spreadsheet software, providing an accurate guidance for data analysis, including photos, tables and pictures to favour understanding and efficiency.

In some cases, the students describe when and how they work on communicability. As a complement, we analyse when the students take communicability into account in their report, if they refer to communicability (or to the technician) together with the description and discussion of the scientific part of the work. The students have various ways of organising their work in the project (S3), regarding communicability. The students' behaviour ranges from a deep reflexion about communicability from the beginning of their project work, to a separation between the scientific part and the writing of the procedure targeted for the test with a technician. In the first case, the students seem to handle the scientific part together with communicability. Some groups explain that they build a strategy in order to facilitate the writing process, mostly by taking notes all along the scientific work, and they report that it is efficient for both completeness and structuring.

Therefore the designers have to reflect in order to find ways to organise efficiently the experimental work, to gain time, to find a way to organise and display data in order to favour analysis, to identify what kind of information is needed and for which purpose it is needed. In their reports, the students refer to the need to master the subject in relation with communicability: "What you understand well, you enunciate clearly (quoted from Boileau) "; "The designer have to master the subject to be able to write for somebody else". All this suggests that the work on communicability incite the students to improve their own work organisation as designers as well as to deepen their reflexion about the scientific ins and outs of their experiment. Some students summarise this point as follows: "I had to improve myself in order to improve the procedure"; "We have to have the same qualities as the procedure"; "Very good organisation skills seem essential to me in order to make the procedure accessible and understandable"; "To build an experimental project de novo and to make it relevant and usable to other people, leads to review our own work schemes, our requisites and rigour".

Testing the procedure with a technician

In the teaching sequence, we introduce a new element with the observation phase of the role-playing game. As a consequence, the designers become aware of the difficulties encountered by the technician. "The first time [they refer to S1] we thought that our procedure was perfect and thus that it was easy to build a procedure. The test proved us that it was all wrong". Students gain the opportunity to identify the difficulties due to the shortcomings of their procedure. The project work is meant to give the students enough time to test and improve their procedure. In fact, in the first semester, the test with the technician was planned at the very end of the project work. It appeared that the students did not plan enough tests as designers. The final test with the technician revealed lots of problems, that were not only related to communicability and there was no time left to solve them. An intermediate test with technicians was thus introduced in the teaching sequence. The test with the technician was given such a high value by the students that some of them organise several intermediate tests and ask friends to play the technician role when classmates were not available. Other students perform one or several careful tests as designers for communicability purposes before the final test. Therefore, it seems that the role-playing game together with the opportunity of final and intermediate tests with a technician, is efficient at stimulating the designers for improvement of the experiment and thus to go deeper in the design process. We can infer from the students final reports that the test with the technician can have several functions that are not limited to communicability criteria fulfilment.

- First, and as seen previously, the test is often used to look for improvement in executability and communicability.

- The test generally has a function of validation of the experiment and procedure, especially when the observer identifies only minor improvements. In this case, the designers report the list of problems and corresponding improvements and explain that the assessment criteria are fulfilled. The students give a high value to what they call "reproducibility". A large majority of students refer to the "reproducibility of the procedure" and a frequent argument for validation is that the experiment provides "the expected results" or "data that are in the expected range of accuracy". But only few students discuss the consistency of the data. They usually do not give details on what "expected" or "reproducibility" means, except in some cases when the data collected by the technician are found not to be consistent with those previously collected by the designers.

- The test is also frequently used for scientific means, mainly to collect new data. This was suggested by the teachers who had to refocus the objectives on the scientific side.

- Last but not least, for some students, the test with the technician sounds as a true research partnership. They explain that the tests give them an opportunity to get new insights on their experiment, and that they had a productive and collaborative discussion with the technician. Some designers express their gratitude to the technicians in their report. This is also visible in the report that the technician gives to the observer after the test, which is very detailed and often displays advices and recommendations. Some students report that the gain is also on the side of the technician, that they get new insights on their own project work from playing the technician role.

As said previously, the tests with the technician make the students highly aware of the impact of the procedure on the quality of the experiment realization and of its results. The production of a reliable procedure, ie that can be properly performed by a technician and that produces reliable results, appears to several students as a true challenge that cannot be fulfilled without testing the procedure with technicians. Two groups of students say that writing a reliable and usable procedure is an unusual but exciting challenge.

CONCLUSION

The role-playing game was introduced in the experimental design learning sequence at first for motivation purposes: students are incited to pay attention to the experimental procedure and write good quality procedure. The teaching module objectives were to make students experience and reflect about the learning process. In order to foster the assessment of the experiment through experience, an observation part was introduced in the role-playing game. It appears that the game strongly emphasize the communicability part in the students' design work. One question is whether the communication part may hinder the scientific part of the students' work. We have analysed the students' written reflections in their final reports according to as list of assessment criteria that was also used by the students. It appears that the students become aware of many problems that occur when performing the experiment with the technician, and that can be classified according to the assessment criteria. The problems that the students notice in the observation phase of the game, may origin from errors in the design of the experiment as well as from imperfections in the writing of the procedure, i.e. communicability. The main point for the students is to avoid errors when running the experiment and to ensure the proper data quality. The procedure is the only way and the only medium that the students can play on as designers. On the other hand they are given the opportunity to check the effects on the performing of the experiment through the tests with technicians. From what the students report, it can be seen that the writing of a good quality procedure is highly demanding, and that the requirements are not only on the communicability side. This leads the students to clarify their aims, to make choices, to go deeper in their understanding of the experimental and data processing techniques, to improve their work organisation, to develop control processes and perform more experimental tests, to work collaboratively with the technicians in a mode, which can be close to a true research partnership.

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